CURRENT DENSITY RECONSTRUCTION WITH MULTI-SCALE GRID APPROACH

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Abstract- **The computational cost of solving electroencephalographic (EEG) or magnetoencephalographic (MEG) inverse problem is extremely high due to the inversion of a matrix configured with a priori information. The matrix size is proportional to the number of points in source grid. We present a multi-scale grid approach to solve the inverse problem using FOCUSS algorithm which is one of the current density reconstruction (CDR) methods and tested the algorithm with simulated EEG data. The multi-scale grid approach dramatically reduces grid points without loss of the resolution.**
Keywords – **inverse problem, electroencephalograhpy, current dipole, grid**

I. INTRODUCTION

The electroencephalographic (EEG) or magnetoencephalographic (MEG) inverse problem is to estimate the current dipole sources underlying measured electric potentials or magnetic fields of the brain outside the head. Among the different approaches to the bioelectromagnetic inverse problem, the current density reconstruction (CDR) methods are widely used. The CDR methods compared to the equivalent current dipole (ECD) methods are computationally intensive due to the large number of source grid points distributed in the whole head. It is inevitable to approach the inverse problem by making uniformly distributed source grid points that cover the whole brain area, though the activations are really localized to several areas. That is a main cause of considering unnecessary grid points as potential source points and making a wasteful computational effort. In order to reduce the computational intensity caused by the multiplicity of potential source locations, this paper presents a method that constructs a multi-scale grid in the CDR methods. The proposed multi-scale grid approach is tested with simulated EEG data sets.

II. METHODOLOGY

A. Background

The EEG inverse problem can be expressed in terms of a linear model. The linear forward model relating the N primary current sources j and the M EEG measurements m can be expressed as

$$m = Gj \qquad (1)$$

where the vector j $(3N \times 1)$ is composed of the $x, y,$ and z components of the current source in the N grid points and the lead field matrix G $(M \times 3N)$ may be viewed as the sensitivity of the sensors to the sources and depends on the geometry and conductivities of the head model described as a volume conductor model.

In practice, of course, the head is not spherical and the electrodes on the head surface do not make point measurements of the electric potential. However, we use a spherical head geometry and assume point measurements in the experimental results presented below.

B. FOCUSS algorithm

The FOCUSS algorithm [1] solves this problem by using a recursive procedure of weighted minimum-norm estimations of the sources. The source estimation at the i-th iteration is written

$$j_i = W_{ai} \, W_{pi} \, (G \, W_{ai} \, W_{pi})^+ m \qquad (2)$$

where $(A)^+$ denotes the Moore-Penrose pseudo-inverse of matrix A. W_{pi} is a diagonal matrix defined by using the previous solution. The kth diagonal element of W_{pi}, $W_{pi}(k,k)$ is defined as follows:

$$W_{pi}(k,k) = W_{pi-1}(k,k) \, j_{i-1}(k) \qquad (3)$$

W_{ai} provides a way to incorporate a priori physiological and anatomical information.

C. FOCUSS with multi-scale grid approach

Incorporating a smoothness constraint lead to long computation times due to the inversion of $W_{ai}^T W_{ai}$. The following multi-spacing grid approach reduces grid points and computation times.

Step1: Make an initial coarse mesh grid that covers the whole brain region.
Step2: Estimate sources with the constructed source grid.
Step3: Check whether each source is activated.

$$p = 1 - P(s > s_k) \qquad (4)$$

where s_k is the intensity of the kth source and $P(s)$ denotes a probability of s which is assumed with Gaussian distribution.
If $p > p_{th}$, the source location is considered as an activated region. In the significantly activated region that is occupied by the activated point source, a new fine grid is substituted for the coarse one.
Step4: Go to step 2 until it reaches minimum grid spacing.

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III. SIMULATIONS

To test FOCUSS with multi-scaled grid approach we simulated EEG data set. These simulated data were generated from two active regions with a three-shell spherical head model, which is centered at point (0,0,0) and the radius of 1. Each region shown in Fig.1 was centered at (0.3, 0.3, 0.3) and (-0.3, -0.3, 0.2) and consisted of nine current dipoles in a 0.02 x 0.02 x 0.02 cube. Background dipole activity with zero-mean white Gaussian distribution was assumed. All the background dipoles were randomly located and oriented in a 1 x 1 x 0.5 volume. We tested the algorithm without background activities and with background activities of SNR=10.

62 Electrodes were uniformly placed on the upper hemisphere of the head.

Initial mesh grid was set with 0.125 and in the next step the mesh-spacing was 0.0313. The grid points in the second step were marked with green circles in Fig.1. The threshold (p_{th}) used to determine weather an estimated dipole is in significantly active state was set to 0.7.

IV. RESULTS

The results of simulations are shown in Fig.1. In the second iteration, the resolution of grid was 0.0313 and the total number of grid points was 571 without noise. 600~800 grid points were constructed with simulated EEG data with noise (SNR=10). A conventional grid with the same resolution would contain 16384 points. The active sources were closely located to the original active regions as shown in Fig.1.

V. CONCLUSION

FOCUSS algorithm with multi-scale grid approach was tested and reduced the number of grid points without change of grid resolution. The multi-scale grid approach is expected to be incorporated with other CDR methods.

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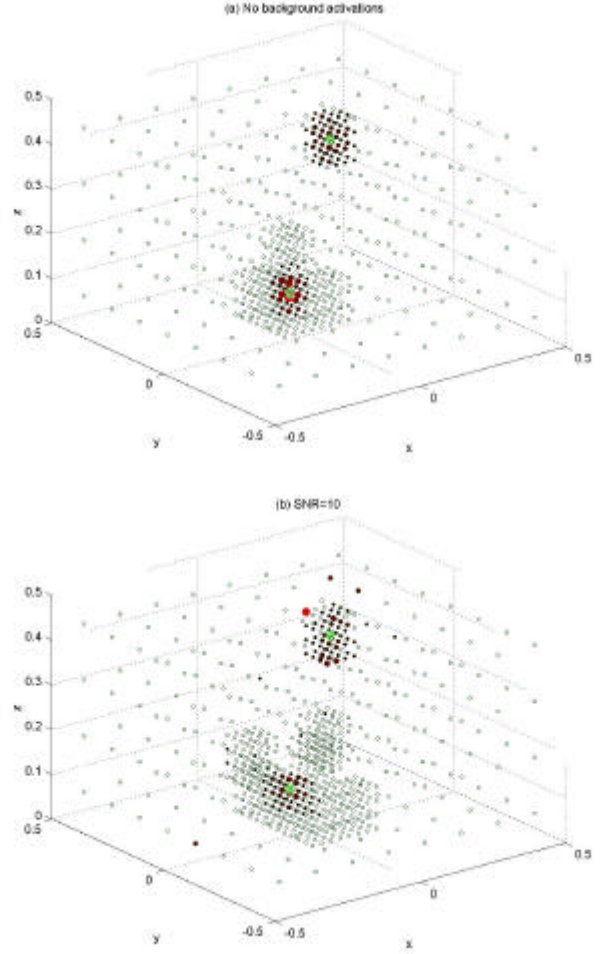
Fig.1 Assumed sources (light green filled circles), constructed multi-scale grid points (dark green vacant circles), and the reconstructed sources (red filled circles). (a) Results with EEG without background activations (b) with background activations, SNR=10.